Review of Dark Matter Tools

Computational Tools for High Energy Physics and Cosmology,

November 2021

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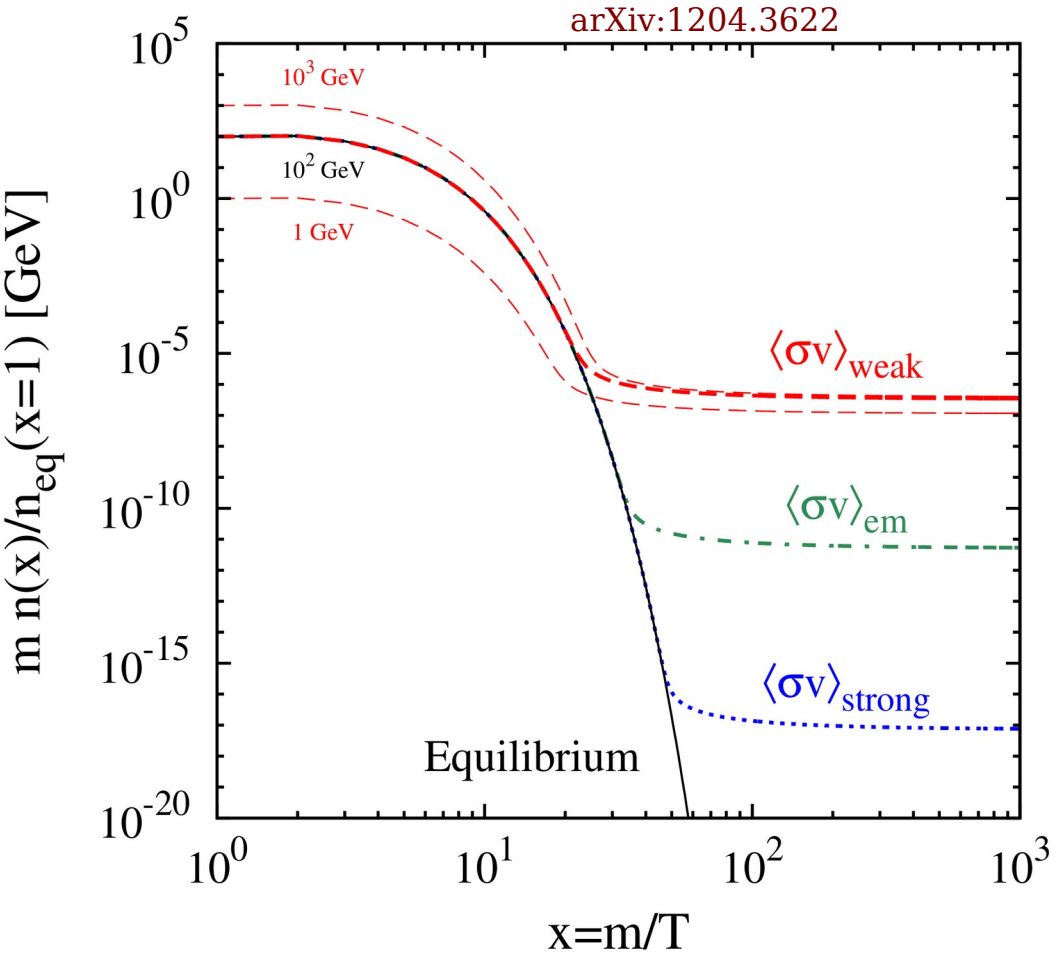
LPC – Clermont Ferrand

Disclaimer

Every review talk needs a disclaimer...



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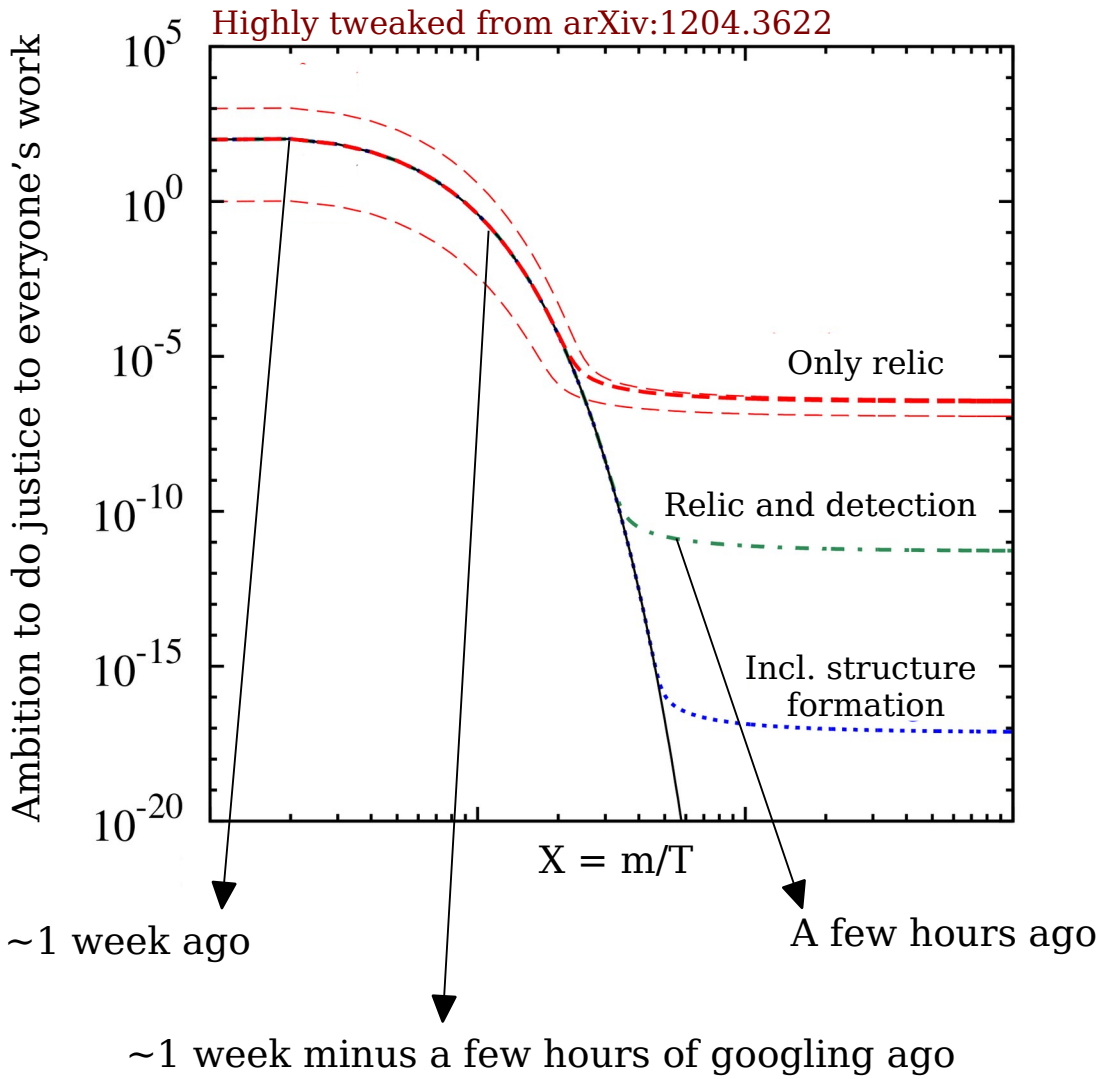

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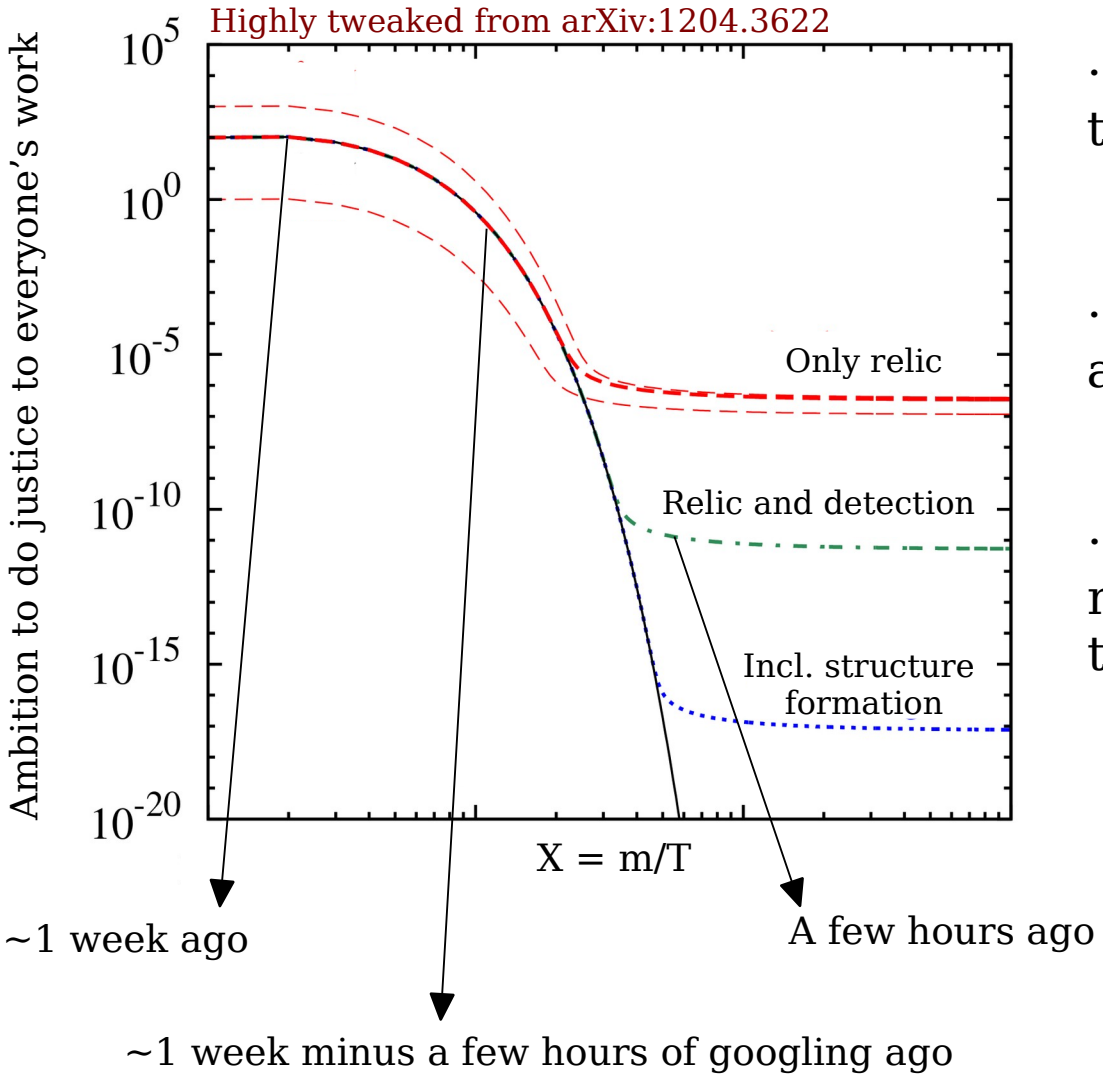

· There are *many* dark matter – related tools available in the community!

· I have not used all of them, let alone all of their functionalities.

· I apologize in advance if I don't mention or misrepresent your favourite tool.

The fact that we've reached a level at which it's actually hard to give a review talk on DM tools is a good thing!

Great resource: last year's DM tools review by C. Arina, slides + arXiv:2012.09462

A bit of history: the MSSM

Already since the early 80's, more and more groups wanted to compute the neutralino relic abundance in the Minimal Supersymmetric Standard Model:

· 28 new particles (+ 17 from the SM).

· All of them can, in principle, coannihilate (either with χ_1^0 or among them).

· In total, this amounts to computing more than 2800 processes.

· And then, you have to solve your Boltzmann equations.

Computing other pheno observables involved a more or less similar process.

People *did* do all that and, in the early 2000's started developing public codes.

→ Common feature: all relevant expressions were *hard-coded*.

This procedure had to be repeated for every new model

Evolution

Some of the general tendencies during the years that followed that drove the development of public codes:

Other dark matter models came in the forefront.

Developments on the TH side

It was realized that there are models which require special treatment.

e.g. light mediators

More observables needed to be computed.

Developments on the EXP side

More and more groups wanted to modify some cosmological assumptions.

e.g. modify radiation Eq. of state or new DM generation mechanisms

Often with an increasing level of complication.

e.g. inclusion of higher-order effects or cosmic-ray propagation

Generalized use meant that codes needed to be user-friendly, portable, modular and fast.

e.g. being able to easily isolate the code functionalities you want

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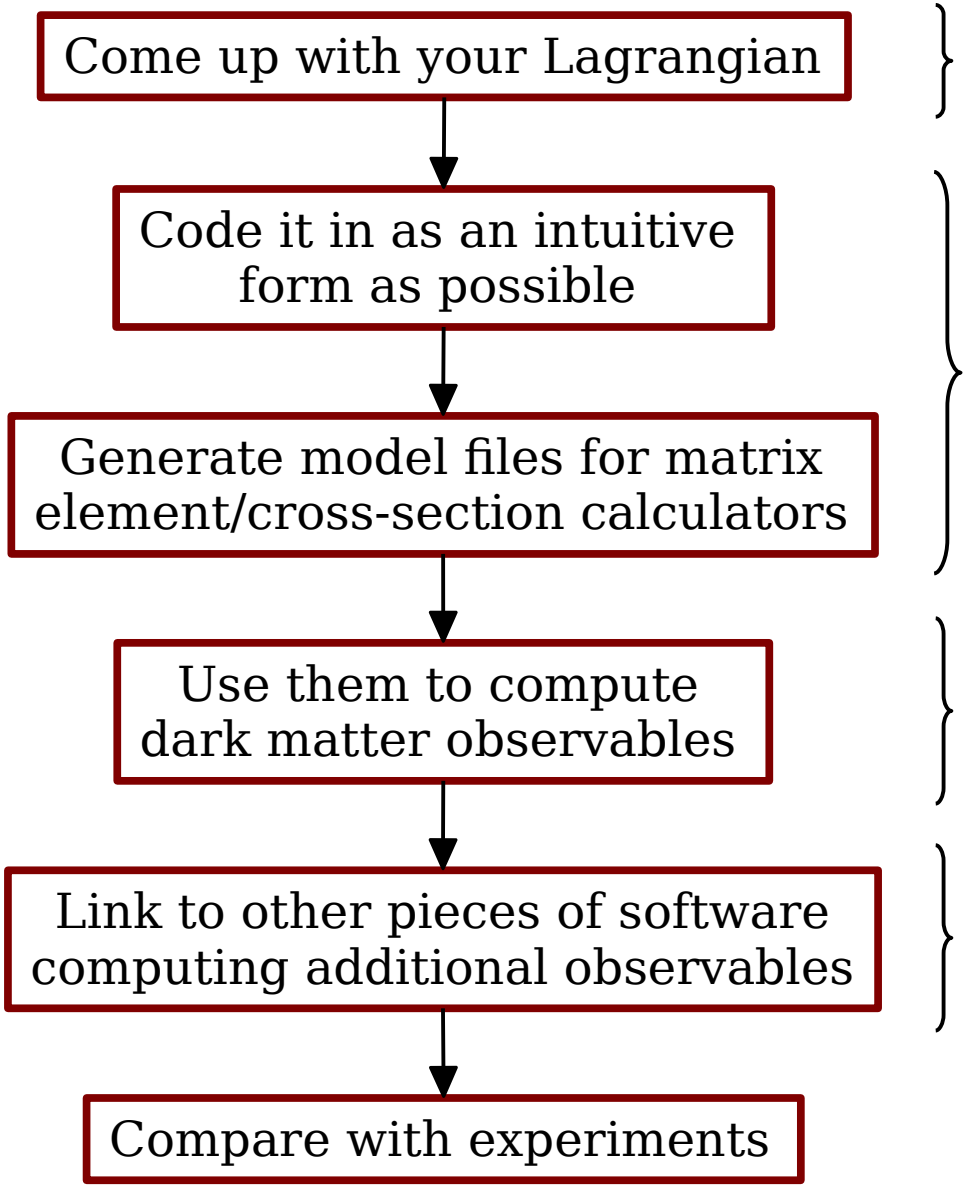
Public codes develop through the interaction between users and developers (*who are also users*!).

A phenomenologist's wishlist



The traditional way (for the moment!).

Model file generators.

e.g. LanHEP, FeynRules, SARAH...

Relic density, direct/indirect detection cross-sections and spectra...

May require additional input (astro etc)

Collider constraints, BBN bounds, flavour observables...

+ Do all of that reasonably fast.

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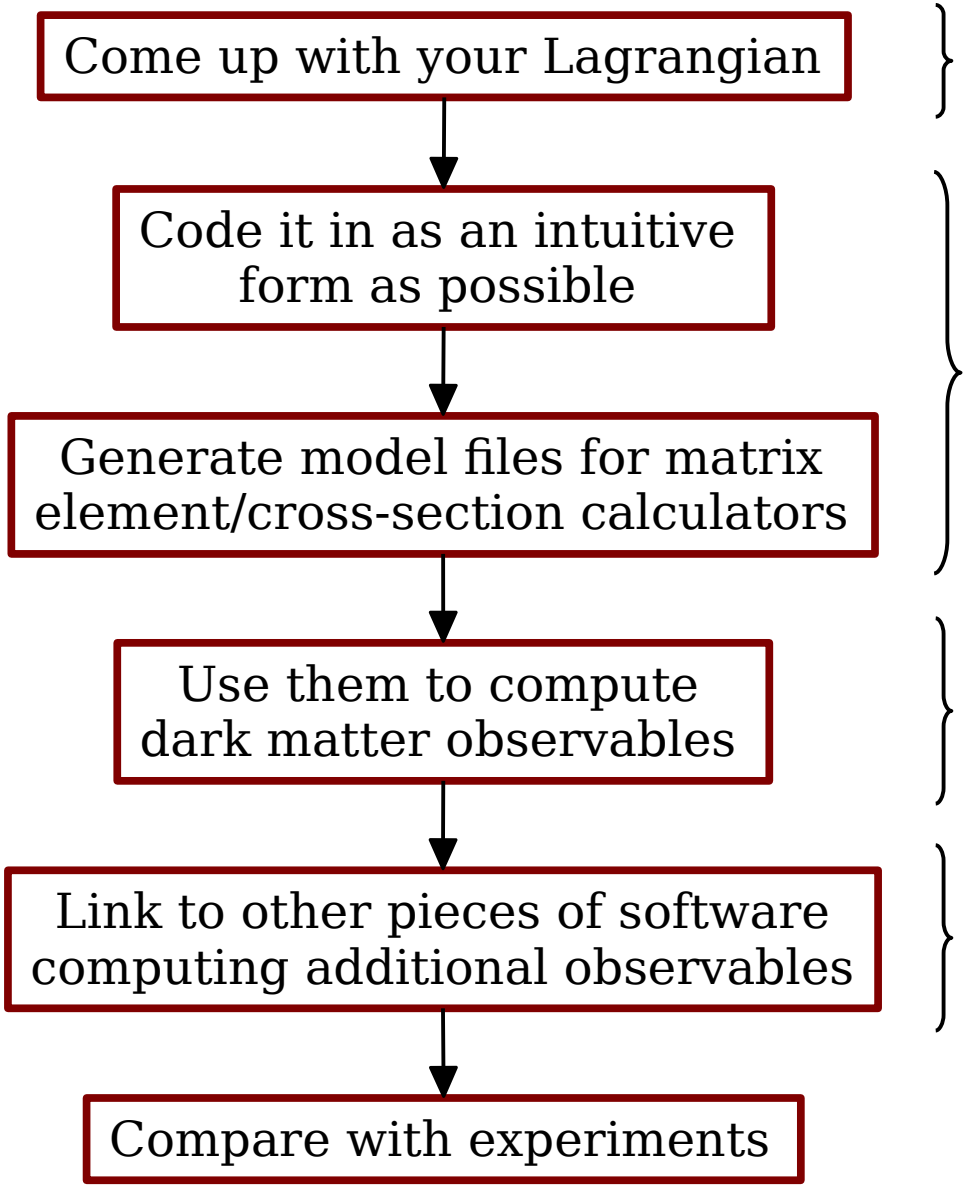

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Keeping in mind that, among other things:

· There are models which require special treatment.

· One might not wish to follow this path.

So which are the dark matter tools?

For the sake of the presentation, let's split them into two categories:

Tools that compute
the DM relic abundance

(but which may also serve other purposes!)

· micrOMEGAs: Generic BSM models.

· DarkSUSY: Generic BSM models.

· SuperIso Relic: MSSM/NMSSN.

· MadDM: Generic BSM models.

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Tools that don't compute the DM relic abundance

(and which definitely serve other purposes!)

· Direct detection: DirectDM, RunDM, RAPIDD, DaMaSCUS, DDCalc...

EFT matching, RGE evolution, scattering in the earth...

· Indirect detection: GALPROP, DRAGON, USINE, CLUMPY, PPPC4DMID, HDMSpectra...

Cosmic ray propagation, annihilation spectra...

· Additional functionalities: DarkBit, DarkHistory...

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· SuperIso Relic: MSSM/NMSSN.

· MadDM: Generic BSM models.

NB: All of these codes also perform (at least) the most standard calculations for direct/indirect detection.

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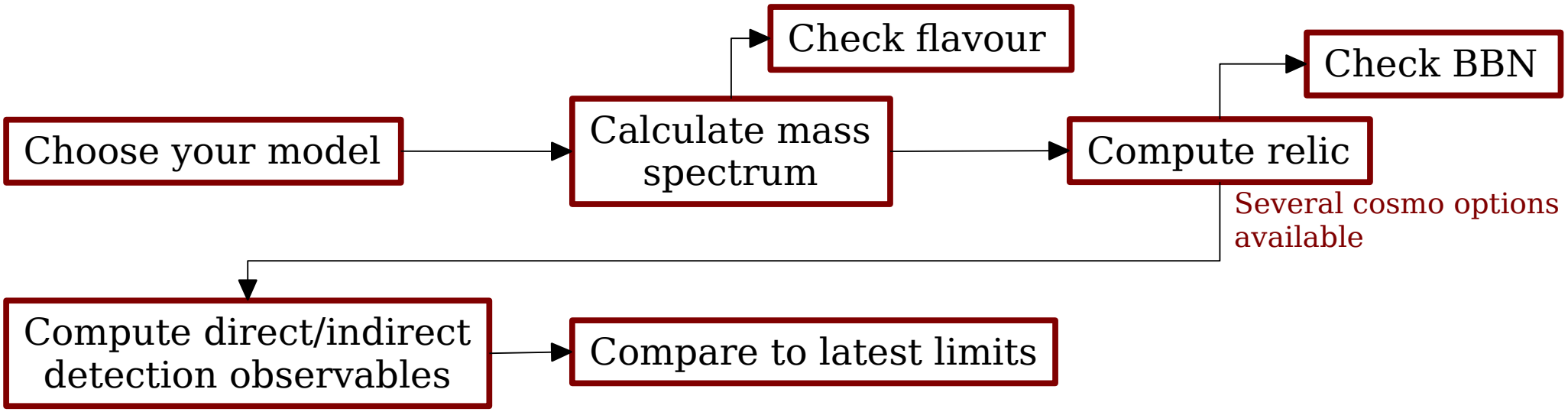
NB: Some of these codes are/can be linked to relic abundance calculation codes.

SuperIso Relic

SuperIso Relic
By Alexandre Arbey, Farvah Nazila Mahmoudi & Glenn Robbins
http://superiso.in2p3.fr/relic/

A mixed C/Fortran code to compute numerous dark matter observables in the MSSM/NMSSM (current version: v4).



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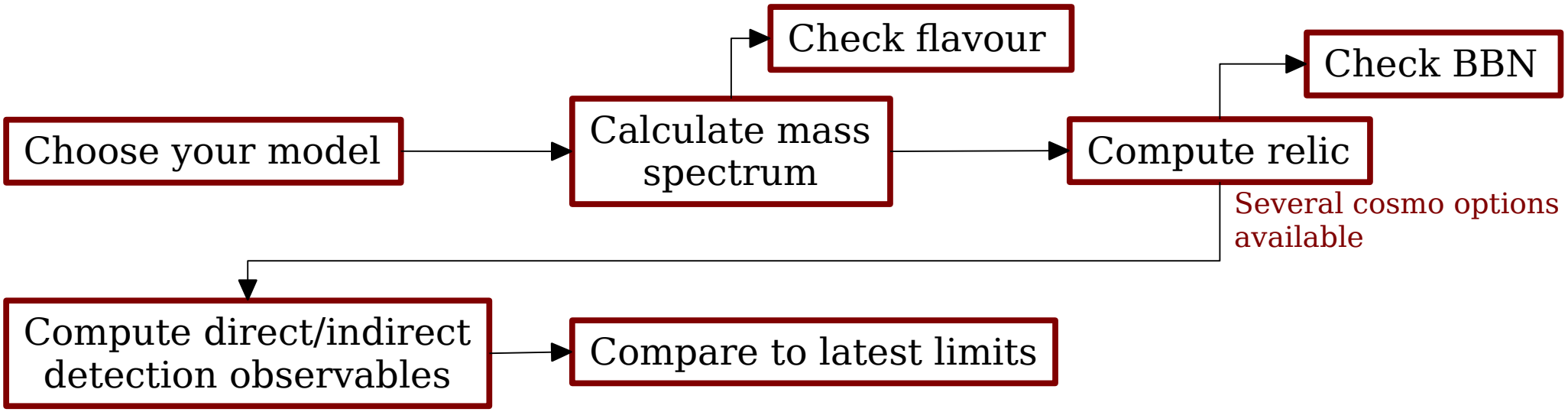


Highlights:

· Comprehensive framework for analysis of neutralino dark matter in (N)MSSM.

· Possibility to modify several cosmological assumptions.

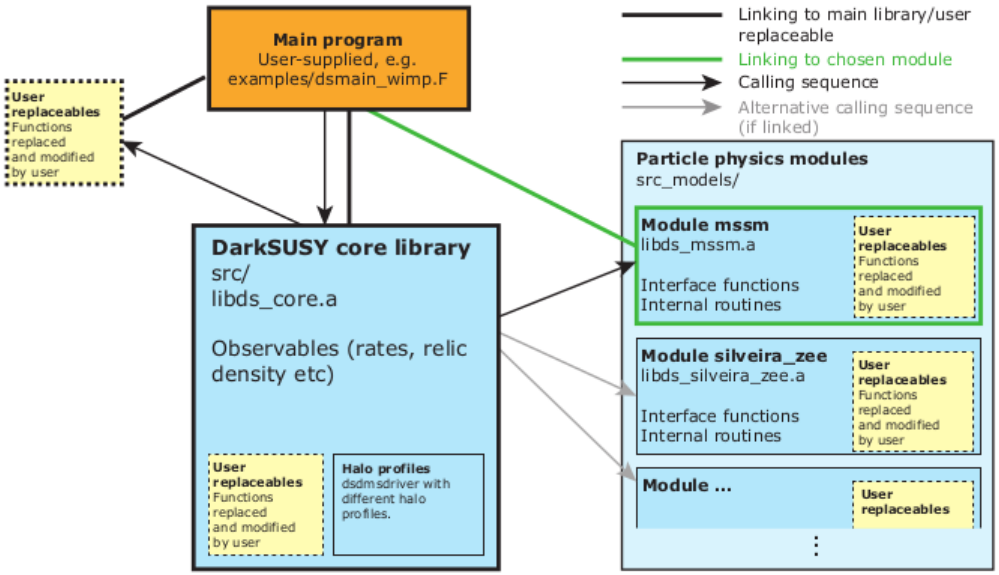
· Readily linked with AlterBBN to compute BBN observables.

· Readily linked with SuperIso to check flavour constraints.

DarkSUSY

https://darksusy.hepforge.org/

A Fortran code to compute numerous dark matter observables for different dark matter candidates (current version: v6).



· Underwent *major* upgrade ~3 years ago, no longer SUSY-specific.

· Freeze-out, direct detection, indirect detection (under different astro assumptions).

· Possibility to link to other, model-specific packages.

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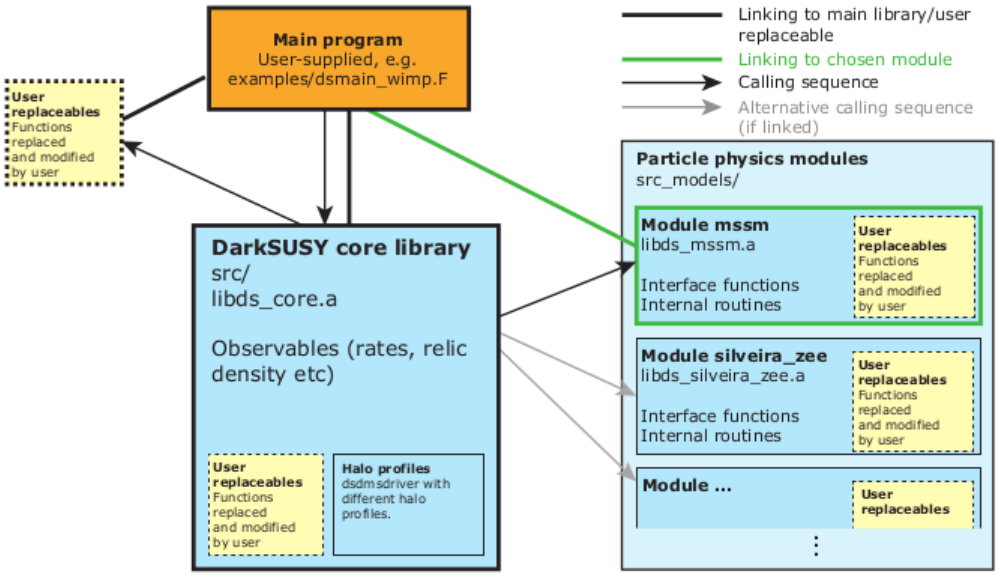

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· Possibility to link to other, model-specific packages.

Highlights:

· Very modular.

· Dark freeze-out computations w/ different sector temperatures.

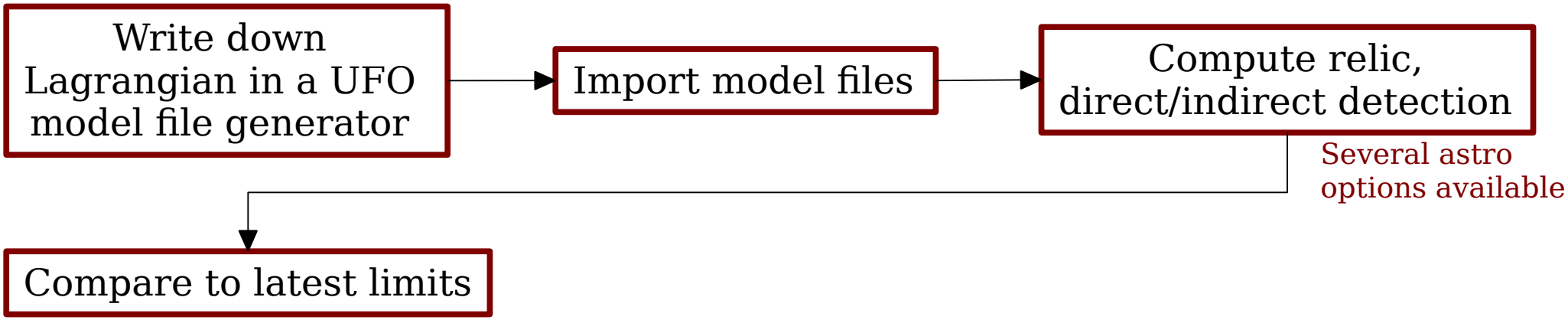
· Possibility to account for late kinetic decoupling, Sommerfeld enhancement.

· Possibility to compute self-interaction effects.

MadDM

https://launchpad.net/maddm/

A Fortran/Python code to compute dark matter observables for generic dark matter candidates (current version: v3).



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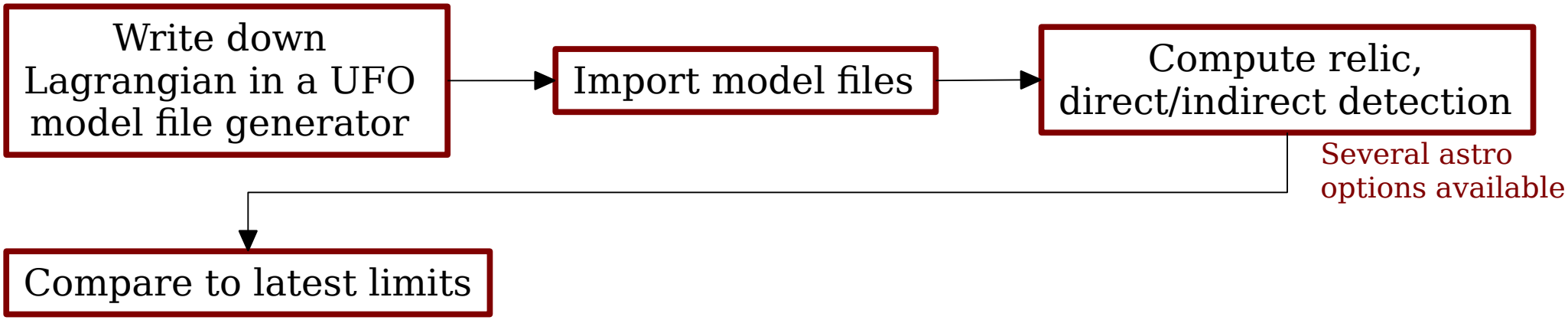


Highlights:

· Handles generic extensions of the SM, no need to compute cross-sections by hand.

· Relies on MG5_aMC, extensively used in collider physics.

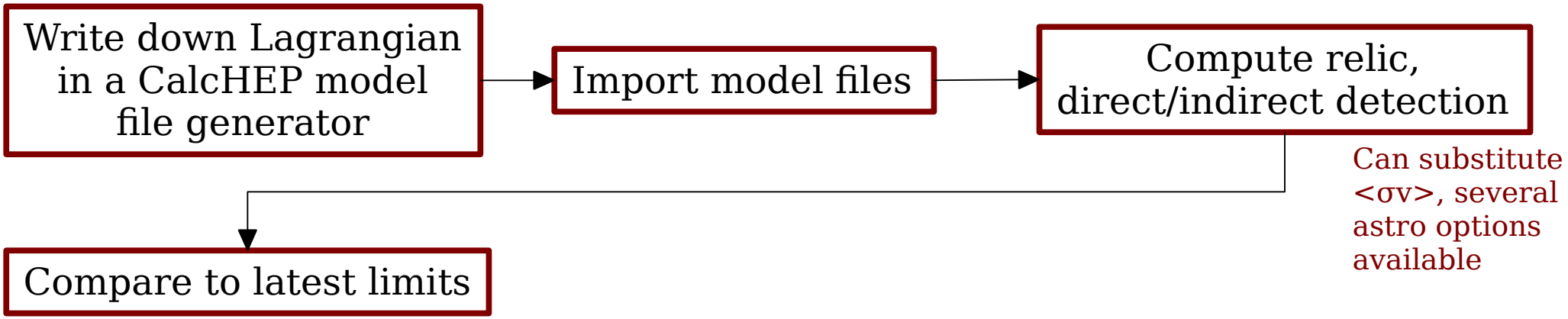
· Readily linked with numerous HEP packages.

· Possibility to compute 2 → n/loop-induced processes for ID via MadLoop.

micrOMEGAs

https://lapth.cnrs.fr/micromegas/

A C/Fortran code to compute dark matter observables for generic dark matter candidates (current version: v5).



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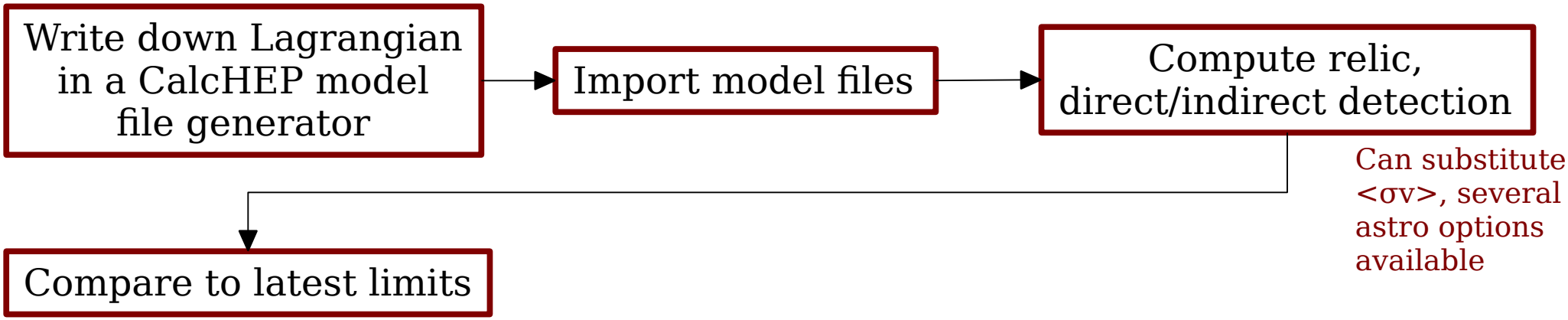

Highlights:

· Can handle multi-component dark matter models.

· Includes semi-annihilations.

· Freeze-in.

· Readily linked with numerous HEP packages.

Summary and outlook

· Dark matter tools have evolved *significantly* during the last few years, and they continue doing so.

· They are now capable of dealing with issues such as: generalized cosmological settings, self-interactions, loop-induced processes, alternative dark matter generations mechanisms, generic dark matter models.

· Which tool you should use really depends on what exactly it is that you're trying to do. Apart from a common core, each code may offer specific functionalities which might be best suited for your purposes.

· Specialized tasks may require specialized codes. Each code has its limitations!

cf codes that don't compute the DM abunance

· All of these tools have been developed by people from *within* our community and they evolve thanks to the feedback *from* the community.

For more details...

· SuperIso Relic tutorial on Monday afternoon, by A. Arbey.

· MicrOMEGAs tutorial on Monday afternoon, by A. Pukhov.

· DarkSUSY tutorial on Wednesday afternoon, by T. Bringmann.

· All the talks on Monday and Wednesday morning.

Thank you!